Appendix II
Request for Proposals

Introduction

This Appendix presents the specific research needs prepared by PG&E and PEER and approved by the JMC for purposes of seeking proposals to satisfy the specified needs. As noted in Section 1.2.2, not all of these requests led to contracts to perform the desired work. In some cases, several investigators were chosen to carry out parallel studies in the same project. The selection of the seven topics is described in Section 1.2.1.

TOPIC 1 – BUILDING VULNERABILITY

Background information

Utilities are in the process of conducting seismic performance studies on a large number of existing buildings with a view toward determining whether seismic upgrading is necessary. In Phase I of the PEER-PG&E program, several projects are examining the state of the practice of performance-based earthquake engineering. The objectives of the current projects are to improve the understanding of the effects of near-source ground motions on the seismic response of buildings, and evaluate assessment methodologies ranging from simple to complex methods.

Phase II of the building vulnerability topic addresses other important aspects of building performance for the purpose deciding on seismic upgrade. The first project is to investigate current methodologies for developing building specific fragility curves. The second project is to investigate improved analysis methods for evaluating seismic performance. Both projects are closely related to projects in the PEER core research program, and they offer an opportunity to apply methodologies developed in PEER for performance based earthquake engineering.

Project 1.A – Evaluation of Building-Specific Fragility Curve Methodologies

The primary objective of this project is to evaluate existing methods for determining fragility curves for typical substation buildings. Fragility curves for a specific building should be consistent for loss estimation and for use in making decisions on retrofit. Previous work has been done for the FEMA / NIBS earthquake loss estimation methodology (Kircher et al., *Earthquake Spectra,* Nov. 1997). This project would include review of current methodologies for fragility curves, determination of appropriateness for typical substation buildings, and identification of improvements. Techniques for developing building specific fragility curves may include use of capacity curves and spectral evaluation of demands. The study should investigate how potential retrofits are reflected in the fragility curves. Specific buildings will be selected in conjunction with PG&E technical staff. Approximately 10 buildings should be considered, ranging from new to old, and low rise to high rise.

Project 1.B – Development of Improved Analysis Methodology for Substation Buildings

The objective for this project is to develop improved practical methods for evaluating the seismic performance of older concrete shear wall and steel frame substation buildings. These types of buildings have historically performed well in moderate earthquakes. However, current analysis techniques and element type testing have been unable to demonstrate this good performance. These substation buildings are typically unmanned and in some cases have minimal equipment other than controls for the substation. The performance goals for major earthquakes are no collapse and access to critical areas within the building.

The investigation is likely to examine the efficacy of improved analysis methods on buildings that have demonstrated good performance in past earthquakes but do not satisfy a code type evaluation. Detailed case studies of typical older substation buildings should be conducted to examine the results using various analysis methods. The final product should be an analysis methodology that: 1) predicts the behavior of older concrete wall / steel frame substation building behavior, and 2) would be usable in a structural engineering office.

TOPIC 2 – ELECTRICAL SUBSTATION EQUIPMENT VULNERABILITY

Background

Phase I of the PEER-PG&E program investigated the seismic performance of a particular model of 196kV, 800A transformer bushing by shaking table testing. Although this model performed well, other designs may not have as high capacity. Other designs of 230kV bushings, and those with higher voltage ratings, which are significantly larger, have failed by oil leakage or porcelain fracture in past earthquakes. The objective of Phase II of this project is to investigate the seismic performance of different designs of 500kV and 230kV transformer bushings, and assess the performance of various retrofit schemes. The project will be organized in two parts, Project 2.A on 500kV porcelain bushing and retrofit, and Project 2.B on other designs of 230kV and 500kV bushings. Project 2.C will investigate the important problem of earthquake dynamics of interconnected equipment.

The first phase of the PEER-PG&E program is also developing new information about the seismic performance of electrical substation equipment including overturning effects and fragility characterization. Phase II includes two related projects on additional aspects of the earthquake performance of electrical substation equipment.

Project 2.A – Seismic Performance of 500kV Porcelain Bushing and Retrofit

The objective of this project is to investigate the seismic performance of ABB 500kV transformer bushing and at least one retrofit scheme. The bushings are to be provided by ABB (tentative). Input motions matching the target spectrum (or portions of the target spectrum) defined by the Moderate Level of IEEE 693-1998 should be used. If the bushing is undamaged structurally during this test, it will undergo electrical and functional tests by the vendor to determine if qualification requirements are met. A second retrofitted bushing will then be tested in a similar fashion, except that the input motions will be increased in increments up to its failure. Instrumentation and procedures similar to those used in Phase I of the bushing testing should be used.

The project should encompass the following components:

- Development of representative input motions, in consultation with PG&E technical staff.

- Design and fabricate any additional hardware needed for testing. Receive and prepare specimen(s) for testing. Perform shake table testing for original bushing.
- Identify retrofit measures. Depending on the retrofitting, it may be done by the proposer or the manufacturer, subject to agreement by PG&E.
- Develop an analytical model that represents the fundamental earthquake behavior of the original and retrofitted bushing.

Project 2.B – Seismic Performance of 230kV and 500kV Bushings of Various Design and Retrofits

This phase of testing includes the investigation of seismic performance of various 230kV and 500kV porcelain transformer bushings produced by different manufacturers. The project will be conducted in conjunction with other West Coast utilities (BC Hydro, Bonneville Power Administration, and Southern California Edison). Transformer bushings of these ratings represent a very vulnerable class of equipment for utilities. While some utilities have chosen to procure composite bushings for new installations and to replace failed equipment, a large inventory of porcelain bushings remains. The review will be limited to the types of bushings still in use by the participating utilities. Project 2.B work therefore involves investigation of the failure modes of various bushing designs used by the participating utilities, developing analytical models, and development and testing of simple retrofit schemes to improve seismic performance. Participating utilities should form a technical committee to work with project investigators.

Preliminary work by participating utilities is needed to assess the types of bushings in their inventories and identify the candidate bushings. The candidate bushings, presumably from different manufacturers, will then be grouped by basic design characteristics, such as structural configuration or gasket type. Available information on failures (or good performances) during past earthquakes will also be gathered from the participating utilities. It is anticipated that specimens for testing will be provided by participating utilities or equipment manufacturers at no cost to this project.

The project should encompass the following aspects:

- Develop possible retrofit schemes for testing that fit the design type of a particular group of candidate bushings. Retrofits must satisfy electrical functionality requirements and be economical to perform in the field. Discussion with utilities and manufacturers will be needed in designing and selecting retrofit alternatives.
- Perform shaking table testing of retrofit schemes. Assess effectiveness of retrofit schemes. Develop analytical models that show the fundamental behavior of the different types of bushings.
- The project funding includes augmentation from other participating utilities.

Project 2.C – Substation Equipment Interaction—Rigid and Flexible Conductor Studies

Substation equipment is connected by both rigid and flexible conductors. During earthquakes, significant interactions and equipment damage due to forces transferred through the connectors have been observed. Flexible buses ("cables") provide relatively little force, provided that they remain slack. Rigid bus (typically aluminum cables) may utilize connectors with small gaps for thermal displacement, thus accommodating some seismic displacement before transferring forces between the connected equipment. Some utilities have implemented slack or loops in flexible and rigid bus to provide flexibility between interconnected equipment. In a current PEER-PG&E project, analytical methods are being used to study the case with equipment connected by flexible bus.

The objective of this project is to investigate by testing the interactions between substation equipment connected by both flexible and rigid bus. It is expected that the results of these investigations would be used to provide guidance in the design of conductor slack and flexibility loops. Scale model testing may be considered if appropriate.

Rigid and flexible bus with connections typically used in the filed should be included in the tests. Flexible bus with various loop shapes and slack lengths should be studied. Rigid bus should be tested with various flexibility loops. The configuration of all specimens must be coordinated closely with PG&E prior to testing to ensure electrical functionality and feasibility. The conductors should be supported at their ends by structures simulating the dynamic response of various types of substation equipment. The support structures should be designed such that their frequencies can be varied as part of the test procedure. Investigators should consider the need for and importance of multiple (more than two) supports.

Earthquake records should be developed in conjunction with PG&E. Records should be modified to match a target spectral shape (or portions of a target spectral shape) agreed upon by the investigators and PG&E.

A detailed work plan will be developed in the first quarter of the project. The work plan should include identifying the types of equipment and their dynamic characteristics, types of conductors and connectors used, selection of earthquake records and criteria for modification, and a test plan. Equipment types to be considered and earthquake records will be chosen in conjunction with PG&E.

The proposal and budget should include design and fabrication of hardware for use in testing, including simulated conductor support structures, conductors, and connecting hardware.

Using the shaking table results, a preliminary examination of analytical methods for interacting equipment should be evaluated.

Project 2.D – Transformer Structure and Turret Amplification Studies

IEEE 693 (Recommended Practices for the Seismic Design of Substations) specifies that a scale factor of 2 be applied to input motions for transformer bushing seismic qualification. This factor is intended to account for amplification of ground motions due to the flexibility of the transformer tank and bushing support structure. Only a limited amount of information is available on the magnitude of the amplification factor.

Transformer bushings are mounted in a variety of ways that differ between manufacturers and models of transformer. Some models mount the bushing(s) on a flat panel on top of the transformer tank. Others may use a turret consisting of a cylindrical shell protruding from the tank, with a cover plate serving as the mounting surface for the bushing. In addition to the flexibility provided by the turret and tank, a significant rotational flexibility may result from bending of mounting plate where the bushing flange is attached. Quantifying the range of this factor has important implications for seismic qualification and fragility of both composite and porcelain transformer bushings.

The objective of this project is to quantify the amplification factor and its variation for different types of transformer structures. Analysis or simple tests, if required, should be used to determine the amplification factor associated with the various equipment types. Recommended improvements, guidelines, or cautions to engineers and designers involved with the design of such structures should be made.

The study should survey most common types of transformer structures and turrets. Similar configurations should be grouped together, if possible, for use by engineers and for fragility analysis. Mountings for 230kV and higher rated bushings should be considered.

In the analysis of dynamic responses of equipment, a range of typical configurations should be examined. The effect of variations of relevant parameters will give insight into the factors affecting amplification of ground motion input into the bushing. The importance of interaction between the bushing and equipment should be investigated. The study is expected to provide response factors and corresponding uncertainties for use in fragility analysis.

The final result of the project should be recommendations in a form suitable for use by engineers and designers of transformer structures to minimize the amplification of motions at the bushing flange.

Previous work also has found that the rocking response and overturning of freestanding electrical equipment due to ground shaking can be quite ordered and predictable. However, three topics of further investigation were identified: (1) the effect of typical anchorages used to prevent toppling, (2) the effect of the vertical component of ground motion, and (3) the effect of inelastic impact. Additional study should be carried out on these topics. The final result should be a practical understanding of the significance of rocking and overturning failure mechanisms, and recommendations for utility procedures to address the significance.

Project 2.E – Protocol for Pre- and Post- Earthquake Data Collections for Substations

The existing utility database containing statistics on substation equipment damaged during earthquake has evolved over time from a relatively ad hoc effort, but still suffers from inconsistencies in the collection strategy, including lack of data on undamaged equipment. In addition, there may be some as yet unrealized benefit to collecting certain equipment data such as conductor slack, prior to earthquake damage. This project would develop recommendations for a protocol to gather substation equipment data both prior to and following an earthquake.

The objective of this project is to develop guidelines that may be employed by utility engineers to gather data at substations prior to and following a significant earthquake. Investigators should focus on data that can be gathered most easily, with the equipment energized. Equipment that is most likely to sustain damage should be emphasized.

Available data on substation equipment fragility should be reviewed. Results on the Phase I fragility projects should be reviewed. The investigation should identify parameters for data collection, and missing data from previous post-earthquake walkdowns. Both pre- and post-earthquake data collection guidelines should be developed. In conjunction with PG&E staff, substations should be selected for testing the guidelines.

TOPIC 3 – SEISMIC VULNERABILITY OF UNDERGROUND CABLE

Background

PG&E and other electric utilities maintain extensive networks of high voltage underground cables (HVUC). These cables are of various vintages (some over 50 years old), and may be vulnerable to ground displacement developed during earthquakes. The project addresses the need for a fundamental examination of the deformation capacity of older underground cables. A Phase I PEER-PG&E project investigated earthquake-induced ground deformation and failure, which is directly relevant to the project.

Project Description

The first objective of the HVUC Seismic Vulnerability project is to identify the type of locations where HVUC is vulnerable to damage from large ground deformations, such as due to fault crossings, landslides, and liquefaction zones. The second objective is to develop methods for estimating deformation capacity of underground cables by testing, analysis, or a combination of the two. Finally, the project should examine the behavior of HVUC to determine what mitigation measures are necessary to prevent cable failures. Coordination with other PEER-PG&E projects that are developing ground deformation is expected, as is coordination with ongoing PG&E testing of HVUC.

The proposal is expected to include the following elements:

- Identify Vulnerable Areas—Identify the types of locations in which HVUC are vulnerable. Methods for determining the vulnerability in terms of ground deformation should be developed.
- Deformation Capacity—Testing and analysis procedures for deterring the deformation capacity of HVUC are expected. It is important to recognize the effect of aged and degraded material in the cables. Functional tests and acceptance criteria should be developed in concert with PG&E.
- Mitigation Measures—Measures to mitigate the effects of ground deformation on HVUC performance should be developed.

TOPIC 4 – GROUND DEFORMATION DATABASE

Background

In the ongoing work of Phase I, updated models for ground deformation are being developed. This work has highlighted some of the shortcomings of the ground deformation database. There is an important need to go back and develop a high quality database before trying to improve the models for ground deformations. A new high quality database will be used in later phases for improving empirical models and for validating analytical models and numerical simulations of ground deformation.

Project Description

In this project, the existing data for ground deformation is being reevaluated. Questionable data are to be removed from the database. Sites for which additional geotechnical parameters are needed are to be identified. (Where feasible, this information will be collected as part of other projects in this overall program.) The emphasis needs to be on the 0.1 to 0.2 m deformations. Ground deformations from the 1995 Kobe earthquake should be included in this database.

TOPIC 5 – GROUND MOTION AND SITE RESPONSE

Background

This topic contains a number of projects related to improving the estimates of earthquake ground motion and response at specific sites.

Project 5.A – Near-fault Ground Motions

To date, attenuation relations have been developed without consideration or near-fault effects such as directivity. The near-fault effects have been parameterized in terms of adjustment factors (such as by Somerville), but have not been incorporated directly into the development of attenuation relations.

In this project, near-fault ground motions should be parameterized in terms of attenuation relations that incorporate near-fault effects including directivity. In addition, site response effects should be evaluated as part of the attenuation relations. That is, the correlation of near-fault effects and site response effects, which have been treated as independent factors in the past, should be considered simultaneously to address possible nonlinear site effects due to near-fault effects.

Project 5.B – Consistent Site Response Estimates

In practice, there is a large variation in the amount of site-specific information that is available for estimating ground motion at a site. In some cases, all that is known is the gross category based on a geologic map. In other cases, some geotechnical site descriptions may be available, and in other cases, detailed site information such as shear-wave velocity, or modulus and damping curves may be available. The current procedures used to estimate the site responses for these different situations are not always consistent. The uncertainty in site response for the cases in which little site information is known should be larger than the uncertainty for the case in which site-specific measurements are available.

In this project, a consistent procedure for estimating site response for various levels of site information is to be developed. This procedure should include appropriate uncertainties.

Project 5.C – Site Characterization of Strong-motion Sites

Many of the sites that have recorded strong ground motions still do not have geotechnical site parameters measured. To improve the models of site response, geotechnical data needs to be collected at these sites. This project will continue the ROSRINE project to drill additional sites. The focus of this phase of the site characterization will be focused on rock sites.

Project 5.D – 3-D Basin Response

Ongoing work in Phase I is addressing using simplified models to predict basin response. Parameter studies are being used to identify the important factor affecting basin response.

In this project, this evaluation needs to produce basin site response factors that can be applied to long period attenuation relations. This project should consider both empirical data and numerical simulations in the development of the model. The model needs to be a probabilistic description including the probability distribution of the data.

TOPIC 6 – FIRE SAFETY AND ELECTRIC POWER

Background

In past earthquakes in California and Japan, electricity has been a significant cause of post-earthquake fires. Although some fires have been electrically ignited immediately after an earthquake, the proportion of electrical causes typically increases with time as power is restored. These later fires are probably due to the reintroduction of power to damaged buildings.

Project Description

In this project, data on fires in past earthquakes will be reviewed to characterize the cases of electrical ignitions. An inventory of fire ignition scenarios will be developed for electrical causes. Using the historical data and the electrical ignition scenarios, the specific conditions that lead to ignitions will be identified, and their relative likelihood in relation to damages caused by earthquakes will be assessed.

Possible mitigation strategies for electrical systems will be identified and evaluated. In particular, the possible use of “Seismic Shut-Off Circuit Breakers” will be considered. The effectiveness of alternative strategies will be evaluated in reducing human safety risks and property damage in earthquakes versus the cost of the strategies.

TOPIC 7 – GROUND MOTION ESTIMATES FOR EMERGENCY RESPONSE

Background

Electrical utility response personnel need information on the levels of damage at facilities as soon as possible following an earthquake. To that end, PG&E has installed 40 strong-motion instruments at the sites of key facilities, and has prepared fragility curves for those facilities and for key equipment. Strong-motion records following an earthquake will be compared to the fragility curves to assess damage within about 10 minutes.

Project Description

The objective of this project is to develop a procedure for rapid estimates of ground shaking following an earthquake. The ground motion estimates should use both recorded ground motions and numerical simulations. The recorded ground motions will include the PG&E strong-motion network and any other strong motion data (from public or private arrays) that can be readily accessed. The numerical simulations should be broadband (e.g. 0.2 to 0.25 Hz) and should be based on source parameters that are rapidly determined. Since the main interest is in large events, the numerical simulations need to account for source dimension. The numerical simulation should be used to produce stable estimates of the ground motion for sites that are not near a strong-motion recording. A procedure for combining the empirical data and the numerical simulations to form a single ground motion map (including gross site conditions) needs to be developed.